

DESIGN A HIGH GAIN UWB MIMO UNIPLANAR MONOPOLE ANTENNA  
WITH FSS ARRAY FOR METALLIC OBJECT MICROWAVE IMAGING

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“To my beloved parents for their praying and supporting. Specially to my lovely wife  
your praying, supporting, and patience keeps me up alive and my lovely kids”.

“To my family, country, the Iraqi government, and all the people for safe life”.



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## ABSTRACT

Ultra-wideband (UWB) system plays an important role in microwave imaging (MWI) applications due to its broad bandwidth, non-ionising radiation, and cost-efficiency. This study involves the design and development phases for the optimum solution of UWB antenna's issues. In the design phase, a compact uniplanar hexagonal UWB monopole antenna with a coplanar waveguide (CPW) feed is designed. The proposed UWB antenna has an oscillate impedance ( $Z_a$ ) of  $50 \Omega$ . A meander-line notch filter is loaded on the designed antenna that achieves a high rejection ( $S_{11} = -1.75$  dB) at the band of 3.0 GHz for 5G mid-band. A T-strip is inserted between the two proposed MIMO antennas to improve the isolation. Moreover, the smallest uniplanar UWB frequency selective surface (FSS) unit cell size ( $0.095\lambda \times 0.095\lambda$ ) is miniaturized on the FR4 substrate. The simulations are compared with the equivalent circuit models of the proposed solutions, then validate with the measurement results. In the development phase, the hexagonal monopole MIMO antenna, the CPW feed, the isolation T-strip, and the  $3 \times 7$  FSS array are assembled to develop the MWI. The isolated MIMO antenna with FSS (IMAF) achieves a bandwidth of 3-11.7 GHz, unidirectional radiation patterns, mutual coupling ( $S_{21}$  about -27 dB) and gain (6-8.5 dBi), and it better than the existing antennas of 3.1-10.6 GHz, -20 dB, and 5.5 dBi, respectively. Additionally, the baggage-scanner scheme is developed as a case study to evaluate the IMAF for near-field MWI. The evaluated images show a resolution of the IMAF is 55% higher than that of the MIMO antenna without an FSS array. Thus, the proposed IMAF detects the smallest ( $0.5 \times 2 \text{ cm}^2$ ) metallic object with a location accuracy of  $\pm 0.5 \text{ cm}$  compared with the recent simulation study of ( $0.6 \times 0.6 \text{ cm}^2$  and  $\pm 1.1 \text{ cm}$ , respectively). A good agreement is observed between the simulated and measured images of the MWI. Consequently, the IMAF is proved to be applicable as part of the detection system for low-cost and non-intricate baggage-scanner imaging to detect metallic objects.

## ABSTRAK

Sistem jalurlebar-ultra (UWB) memainkan peranan penting dalam aplikasi pengimejan gelombang mikro (MWI) kerana lebar jalur yang luas, sinaran tak mengion, dan kecekapan kos. Kajian ini melibatkan fasa rekabentuk dan pembangunan untuk penyelesaian optimum masalah antenna UWB. Dalam fasa rekabentuk, sebuah antenna padat ekakutub UWB heksagon satah sesisi dengan suapan pandu gelombang sesatah (CPW) telah direkabentuk. Antenna UWB yang dicadangkan mempunyai galangan berayun ( $Z_a$ ) sebanyak  $50 \Omega$ . Sebuah penapis takuk garisan liku dimuatkan pada antenna yang direkabentuk yang mencapai penolakan tinggi ( $S_{11} = -1.75$  dB) pada jalur 3.0 GHz untuk band 5G. Sebuah jalur-T telah dimasukkan di antara dua antenna MIMO yang dicadangkan untuk meningkatkan pemencilan. Tambahan lagi, saiz sel unit terkecil permukaan pemilihan frekuensi (FSS) UWB satah sesisi ( $0.095\lambda \times 0.095\lambda$ ) telah dipadatkan pada substratum FR4. Simulasi dibandingkan dengan model litar bersamaan bagi penyelesaian yang dicadangkan, kemudian disahkan dengan hasil pengukuran. Dalam fasa pembangunan, antenna MIMO ekakutub heksagon, suapan CPW, pemencilan jalur-T, dan  $3 \times 7$  tatasusunan FSS telah dihipunkan untuk membangunkan MWI. Antenna MIMO terencil dengan FSS (IMAF) mencapai lebar jalur 3-11.7 GHz, corak sinaran searah, gandingan bersama ( $S_{21}$  bout -27 dB) dan keuntungan (6-8.5 dBi), dan lebih baik daripada antenna sedia ada 3.1-10.6 GHz, -20 dB, and 5.5 dBi, masing-masing. Di samping itu, skima pengimbas bagasi telah dibangunkan sebagai kajian kes untuk menilai IMAF bagi MWI medan berhampiran. Imej yang dinilai menunjukkan resolusi IMAF 55% lebih tinggi daripada antenna MIMO tanpa tatasusunan FSS. Oleh itu, IMAF yang dicadangkan mengesan objek logam yang terkecil ( $0.5 \times 2 \text{ cm}^2$ ) dengan ketepatan lokasi  $\pm 0.5 \text{ cm}$  berbanding dengan kajian simulasi baru-baru ini ada ( $0.6 \times 0.6 \text{ cm}^2$  dan  $\pm 1.1 \text{ cm}$ ). Persetujuan yang baik dipatuhi antara imej MWI yang telah disimulasi dan diukur. Akibatnya, IMAF dibuktikan dapat digunakan sebagai sebahagian daripada sistem pengesanan

untuk pengimejan pengimbas bagasi kos rendah dan tidak rumit bagi mengesan objek logam.



## CONTENTS

<b>TITLE</b>	<b>i</b>
<b>DECLARATION</b>	<b>ii</b>
<b>DEDICATION</b>	<b>iii</b>
<b>ACKNOWLEDGEMENT</b>	<b>iv</b>
<b>ABSTRACT</b>	<b>v</b>
<b>ABSTRAK</b>	<b>vi</b>
<b>CONTENTS</b>	<b>viii</b>
<b>LIST OF TABLES</b>	<b>xii</b>
<b>LIST OF FIGURES</b>	<b>xiii</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xviii</b>
<b>LIST OF SYMBOLS</b>	<b>xx</b>
<b>LIST OF APPENDICES</b>	<b>xxiii</b>
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Motivation	1
1.2 UWB standard and regulation	2
1.3 Research background	4
1.4 Problem statement	5
1.5 Research objectives	7
1.6 Research scope	7
1.7 Significant contributions of the research	8
1.8 Thesis organisation	10
<b>CHAPTER 2 LITERATURE REVIEW OF UWB ANTENNA FOR MWI</b>	
<b>APPLICATIONS</b>	<b>12</b>
2.1 UWB systems for MWI applications	13
2.2 Review of UWB antenna for MWI	16
2.3 Types of planar UWB antenna	18
2.3.1 Tapered slot Vivaldi UWB antenna	18

2.3.2 Antipodal Vivaldi UWB antenna (AVA)	21
2.3.3 Planar slot monopole UWB antenna	23
2.3.4 Planar patch monopole UWB antenna	26
2.3.5 Discussion	29
2.4 Critical review in UWB monopole antenna: issues and trade-offs	30
2.4.1 Bandwidth	31
2.4.2 Size miniaturization	34
2.4.3 Directional radiation pattern	37
2.4.4 Gain	43
2.4.5 Mutual coupling for MIMO	45
2.4.6 Interference	46
2.5 Selected issues, study direction, and research gap of UWB antenna	47
2.6 Review of the design concepts and theory	50
2.6.1 Theory of UWB monopole antenna	50
2.6.2 Theory of CPW feed	52
2.6.3 Theory of notch filter	54
2.6.4 Theory of MIMO isolation	55
2.6.5 Theory of FSS	57
2.7 Summary	58

## **CHAPTER 3 METHODOLOGY OF DESIGN AND DEVELOPMENT**

<b>UWB ANTENNA FOR MWI</b>	<b>59</b>
3.1 Research phases	59
3.2 Design framework	62
3.3 Design phase	63
3.3.1 Equivalent circuit model	63
3.3.2 CPW feed	66
3.3.3 Uniplanar patch UWB monopole antenna	68
3.3.3.1 Design and configuration of hexagonal monopole antenna	70
3.3.3.2 Numerical derivation of the proposed antenna structure	75
3.3.3.3 Equivalent circuit of Antenna #3	80



3.3.4 Notch filter meander-line strip for band rejection	81
3.3.4.1 Parametric study meander-line strip	83
3.3.4.2 Equivalent circuit model antenna with notch	84
3.3.5 Isolation of UWB MIMO antenna (IMA)	85
3.3.5.1 MIMO without isolation	85
3.3.5.2 MIMO with isolation	87
3.3.5.3 Equivalent circuit of MIMO antenna	88
3.3.6 FSS array for high gain and UDRP	90
3.3.6.1 FSS unit cell design and operation mechanism	90
3.3.6.2 FSS equivalent circuit model	91
3.3.6.3 FSS simulation and fabrication	94
3.4 Development of UWB MIMO antenna with FSS array (IMAF)	96
3.5 CST microwave studio simulation	99
3.6 Fabrication process	100
3.7 Measurement procedures	101
3.8 Development/detection phase	104
3.8.1 Microwave detection simulation setup	105
3.8.2 Microwave detection measurement setup	106
3.8.3 Microwave imaging processing	109
3.9 Validation and evaluation phase	111
3.10 Conclusion	112
<b>CHAPTER 4 RESULTS ANALYSIS AND EXPERIMENTAL VALIDATION</b>	<b>114</b>
4.1 Validation results of design hexagonal UWB antenna	114
4.1.1 Side-feed line antenna	114
4.1.2 Vertex-feed line antenna	115
4.1.3 Equivalent circuit model	118
4.2 Results of notch filter	120
4.2.1 Meander-line strip parametric study	120
4.2.1.1 Meander-line horizontal length ( $L_s$ )	121
4.2.1.2 Meander-line vertical length ( $L_z$ )	122
4.2.1.3 Meander-line strip width ( $ths$ )	123
4.2.2 Results validation of notch filter	124

4.2.3 Equivalent circuit model antenna with notch	127
4.3 Results validation of UWB MIMO isolation	129
4.3.1 MIMO without isolation	129
4.3.2 MIMO with isolation	131
4.3.3 Equivalent circuit of MIMO antenna	136
4.4 Results validation of FSS array	137
4.4.1 FSS simulation and equivalent circuit	137
4.4.2 Prototype experimental results of FSS array	139
4.5 Results of UWB MIMO with FSS reflector (IMAF)	140
4.5.1 Computing of IMAF	141
4.5.2 Measurement validation	147
4.6 Evaluation phase and validation of MWI scanner	151
4.6.1 Validation of IMAF	151
4.6.2 Detection capability	154
4.6.3 Evaluation of MWI antennas	155
4.7 Conclusion	161
<b>CHAPTER 5 CONCLUSIONS AND FUTURE RECOMMENDATIONS</b>	<b>162</b>
5.1 Contributions and findings	162
5.2 Recommendations and future work	165
<b>REFERENCES</b>	<b>167</b>
<b>APPENDICES</b>	<b>184</b>
<b>LIST OF PUBLICATIONS AND AWARDS</b>	<b>201</b>
<b>VITA</b>	<b>204</b>

## LIST OF TABLES

1.1	Standards UWB band in the world	4
2.1	Literature evaluation based on bandwidth enhancement	33
2.2	Literature evaluation based on size miniaturization	37
2.3	Literature evaluation based on UDRP	42
2.4	Literature evaluation based on gain	45
2.5	The Punch-mark articles and specifications according to each issue of the monopole antenna	49
3.1	Dimensions and parameters of reference Antenna #1	72
3.2	Validation of calculated and simulated antenna parameters	78
3.3	Antenna #3 parameters	79
3.4	The parameters of the proposed MIMO monopole antenna	86
4.1	The calculated parameters of equivalent circuit	119
4.2	The optimum parameters of equivalent circuit	128
4.3	The specifications evaluation between the proposed and punch-mark studies of the monopole antenna	160
4.4	Evaluation between the developed MWI and the literature	160

## LIST OF FIGURES

2.1	Basic structure for literature review	13
2.2	Different radar approaches	14
2.3	Cylindrical scanning system (a) mono-static and (b) bi-static	14
2.4	Linear scanning MWI system (a) mono-static and (b) bi-static	15
2.5	Spherical scanning MWI system using multi-static approach	16
2.6	Taxonomy of literature on UWB antenna for MWI	17
2.7	Techniques related to tapered slot Vivaldi antennas	20
2.8	Techniques related to antipodal Vivaldi antennas	23
2.9	Techniques related to slot monopole UWB antennas	26
2.10	Techniques related to planar monopole UWB antennas	29
2.11	Enhancement of antenna bandwidth in (a) and (b)	33
2.12	Miniaturized antenna size using (a) slots and (b) cuts	36
2.13	(a) Antenna reflector and (b) cylindrical FSS	40
2.14	(a) Flexible array antenna and (b) graphene array antenna	44
2.15	UWB antenna (a) U-slot and (b) strip and EBG	47
2.16	Research area among the literature classifications	48
2.17	Circular disc monopole antenna	50
2.18	Schematic of UWB antenna operation principle	51
2.19	CPW feed	53
2.20	The notch filter and equivalent circuit	55
2.21	Two linear MIMO elements	56
2.22	Basic square-ring FSS unit cell and equivalent circuit	58
3.1	Research process flowchart	60
3.2	Design framework flowchart	62
3.3	Parallel RLC circuit	64

3.4	UWB antenna equivalent circuit	65
3.5	CPW structure	67
3.6	The macro calculation of CPW geometry	68
3.7	Various regular-shaped antennas with different configurations	70
3.8	Geometries of Antenna #1 for (a) side and (b) top views	71
3.9	The configuration of the design steps for the proposed antenna	75
3.10	(a) Structure of derived monopole antenna, (b) design parameters, and (c) the equivalent dipole	76
3.11	(a) The proposed Antenna #3 structure with CPW feed and (b) fabrication prototype	79
3.12	Simulation of the suggested circuit by using CST schematic	81
3.13	(a) The geometry and (b) equivalent circuit of meander-line strip (c) dimensions of the UWB antenna	82
3.14	Fabrication prototype of UWB antenna with notch filter	84
3.15	The ECM schematic of the antenna and meander-line	85
3.16	The proposed MIMO with spacing distance ( $Da$ )	86
3.17	The proposed MIMO $Da = 42$ mm with the parasitic stub (Antenna #4)	88
3.18	Equivalent circuit model of isolated MIMO antenna	89
3.19	The ECM schematic of the MIMO antenna	89
3.20	Geometry of (a) FSS array, and (b) FSS unit cell	90
3.21	FSS equivalent circuit model	92
3.22	(a) FSS unit cell simulation setup and (b) equivalent circuit	95
3.23	(a) Photograph of the FSS array prototype $54 \times 36$ elements, (b) zoom view of the unit cells	95
3.24	3D schematic view of the proposed Antenna #5	97
3.25	Side view of antenna with FSS array	97
3.26	Prototype of IMAF Antenna #5	98
3.27	The simulation setup of the antenna design	100
3.28	Measurement equipment (a) R&S ZNB14 VNA, (b) R&S SMBV100A VSG, (c) R&S FSH20 SA, (d) BHA 9118 horn antenna, and (e) measurement S-parameters	102

3.29	The measurement setup of radiation pattern and in anechoic chamber	103
3.30	Bi-static free space FSS measurement (a) opposite and (b) adjacent schemes	104
3.31	Scheme setup of testing the model	105
3.32	(a) Simulated bag model (b) linear scanning scheme	106
3.33	Scheme setup of testing a sample with the proposed antenna	107
3.34	(a) Experiment scanning (b) photo baggage scanner testing	108
3.35	Imaging scheme configuration	109
3.36	The process of monitoring the measured reflected signals	111
4.1	(a) Fabrication prototype (b) measurement and simulation return loss	115
4.2	Measurement and simulation $S_{11}$ of Antennas #1 and #3	116
4.3	The measured and simulated radiation patterns normalized at 4.0 GHz and 5.7 GHz for Antenna #3	117
4.4	The reference antenna simulated impedance (Real part) Antenna #3	118
4.5	Validation of simulated and calculated antenna impedances (Real part)	118
4.6	Validation of simulated and calculated impedances (Imaginary part)	119
4.7	Impedance validation of the antenna and suggested equivalent circuit (a) Real part (b) Imaginary part	120
4.8	VSWR of meander line strip with a different length of $L_s$	121
4.9	VSWR of the meander-line strip with a different length of ( $L_z$ )	122
4.10	VSWR of the meander-line strip with a different width $ths$	123
4.11	The current distribution (a) at 3.0 GHz and (b) at 4.09 GHz	124
4.12	Simulated and measured $ S_{11} $ of the proposed antenna with the strip	125
4.13	Simulated and measured VSWR of the antenna with the strip	125
4.14	The measured (black) and simulated (red) antenna patterns (a) 4 GHz E-plane, (b) 4 GHz H-plane, (c) 5.7 GHz E-plane, (d) 5.7 GHz H-plane	126

4.15	Antenna gain and radiation efficiency	127
4.16	ECM impedance validation real part in (a) and imaginary part in (b)	128
4.17	Simulated and measured S-parameters of MIMO antenna without strip	130
4.18	Gain and efficiency of Port-1	130
4.19	Simulated and measured S-parameters of MIMO Antenna #4 with isolation strip	131
4.20	The ECC of the isolated MIMO antenna	132
4.21	The diversity gain of the proposed MIMO antenna	133
4.22	Simulated current distribution Port-1 isolated MIMO at 4 GHz	133
4.23	Gain and efficiency of MIMO antenna with the strip (Port-1)	134
4.24	Simulated and measured normalized radiation patterns (a) 4 GHz, (b) 5 GHz, and (c) 6 GHz are H plane, (d) 4 GHz, (e) 5 GHz, and (f) 6 GHz are E plane of Port-1 isolated MIMO antenna	135
4.25	Impedance validation Real part in (a) and Imaginary part in (b)	136
4.26	Simulated transmission and reflection coefficients	138
4.27	Current distribution on FSS unit cell at (a) 4.0 GHz, and (b) 8.0 GHz	139
4.28	The simulated and measured S-parameters magnitude of FSS	140
4.29	Simulated study of antenna bandwidth and gain at the different $Dz$	141
4.30	Study of front and reflected unwrap antenna phase at the distances of $Dz$	142
4.31	Simulated magnitude S-parameters of IMAF (Antenna #5)	143
4.32	Simulated gain MIMO antenna with FSS of Port-1	144
4.33	The simulated the envelope correlation coefficient and diversity gain	144
4.34	Simulated $S_{21}$ magnitude at different distances $Dz$	145
4.35	Reflection path of IMAF	146

4.36	(a) Front view current distribution, (b) top view electric field of IMAF Antenna #5 at 3 GHz Port-1	147
4.37	Measured magnitude S-parameters of the MIMO antenna with FSS	148
4.38	Gain validation and efficiency of Port-1 IMAF	149
4.39	Simulated (—) and measured (----) radiation pattern normalized H-planes in (a) 4 GHz, (b) 5 GHz, (c) 6 GHz and E-plane in (d) 4 GHz, (e) 5 GHz, (f) 6 GHz of Port-1 IMAF Antenna #5	150
4.40	The scattering data of MIMO antenna with and without FSS array	152
4.41	2D images of IMAF (a) simulated model (b) the tested handbag with $1 \times 2 \text{ cm}^2$ metal object	153
4.42	Experimental 2D imaging with $1 \times 2 \text{ cm}^2$ object using (a) IMAF (b) IMA	155
4.43	2D images of IMA evaluation (a) simulated model (b) testing	157





## LIST OF ABBREVIATIONS

<i>2D</i>	- Two-dimensional
<i>3D</i>	- Three-dimensional
<i>AMC</i>	- Artificial magnetic conductor
<i>AND</i>	- Logic operator
<i>AUT</i>	- Antenna under test
<i>AVA</i>	- Antipodal Vivaldi antenna
<i>BiD</i>	- Bidirectional radiation pattern
<i>BW</i>	- Bandwidth
<i>CPW</i>	- Coplanar waveguide feed
<i>CST</i>	- Computer simulation technology
<i>DG</i>	- Diversity gain
<i>DGS</i>	- Defected ground structure
<i>EBG</i>	- Electromagnetic band-gap
<i>ECC</i>	- Envelope correlation coefficient
<i>ECM</i>	- Equivalent circuit model
<i>EM</i>	- Electromagnetic
<i>EMI</i>	- Electromagnetic interference
<i>FBW</i>	- Fractional bandwidth
<i>FCC</i>	- Federal Communications Commission USA
<i>FIT</i>	- Finite integration technique
<i>FKEE</i>	- Faculty of Electrical and Electronic Engineering
<i>FR4</i>	- Glass-reinforced epoxy laminate material
<i>FSS</i>	- Frequency selective surface
<i>GPR</i>	- Ground-penetrating radar
<i>HPBW</i>	- Half power beamwidth
<i>IEEE</i>	- Institute of Electrical and Electronics Engineers
<i>IFFT</i>	- Inverse fast Fourier transform

<i>IMA</i>	- Isolated UWB MIMO antenna
<i>IMAF</i>	- Isolated UWB MIMO antenna with FSS array
<i>ISM</i>	- Industrial, scientific and medical radio band
<i>MATLAB</i>	- Matrix laboratory software
<i>MIMO</i>	- Multiple-input and multiple-output
<i>MS Excel</i>	- Microsoft Excel
<i>MWI</i>	- Microwave imaging
<i>OD</i>	- Omnidirectional radiation pattern
<i>OFDM</i>	- Orthogonal frequency division multiplexing
<i>PCB</i>	- Printed circuit board
<i>PHMAS</i>	- Printed hexagonal monopole antenna side-feed
<i>PHMAV</i>	- Printed hexagonal monopole antenna vertex-feed
<i>PL</i>	- Path length
<i>RF</i>	- Radio frequency
<i>RLC</i>	- Resistor, inductor, and a capacitor resonant circuit
<i>Rx</i>	- Receiver
<i>SAR</i>	- Specific absorption rate value
<i>SMA</i>	- SubMiniature version A 50 ohm connector
<i>SNR</i>	- Signal-to-noise power ratio
<i>SRR</i>	- Split ring resonator
<i>STW</i>	- See-through wall
<i>SVM</i>	- Support vector machine
<i>TE</i>	- Transverse electric
<i>Tx</i>	- Transmitter
<i>UDRP</i>	Unidirectional radiation pattern
<i>UTHM</i>	- Universiti Tun Hussein Onn Malaysia
<i>UWB</i>	- Ultra-wideband
<i>VNA</i>	- Vector network analyzer
<i>VSWR</i>	- Voltage standing wave ratio
<i>WiMAX</i>	- Worldwide interoperability for microwave access
<i>WLAN</i>	- Wireless local area network
<i>WPAN</i>	- Wireless personal area network

## LIST OF SYMBOLS

$dB, dBi$	-	Logarithmic scale unit, and Isotropic logarithmic scale unit
$S_{11}, S_{22}$	-	Reflection coefficients
$S_{21}, S_{12}$	-	Transmission coefficients
$cm, cm^2, cm^3$	-	Centimeter, square centimeter, cubic centimeter are units
$mm, mm^2, mm^3$	-	Millimeter, square millimeter, cubic millimeter are units
$GHz$	-	Gigahertz is unit
$MHz$	-	Megahertz is unit
$Da$	-	Distance between the MIMO antenna elements
$Dz$	-	Distance between the antenna and FSS array
$D_o$	-	Largest dimension of the antenna
$Rd$	-	Near-field region
$\lambda$	-	Wavelength
$\lambda_o$	-	Wavelength of resonance frequency
$f, f_o, f_r$	-	Resonant frequency
$f_c$	-	Centre frequency
$f_L$	-	Lowest frequency
$f_H$	-	Highest frequency
$\Omega, nH, pF$	-	Ohm, nanohenry, picofarad are units
$N$	-	Number of articles
$\epsilon_r, \epsilon_{reff}$	-	Dielectric constant, Effective dielectric constant
$L$	-	Monopole antenna length
$W$	-	Monopole antenna width
$r$	-	Effective radius of the cylindrical monopole antenna
$p$	-	Gap between the ground plane and the patch
$k$	-	Constant for the FR4 substrate
$Wf$	-	Width of the feed line

$H$	-	Substrate thickness
$La, Wa$	-	Substrate length and width
$S, S_1, S_2$	-	Patch sides length
$a^\circ$	-	Patch sides angle
$R$	-	The radius of the hexagonal patch
$L_f, W_f$	-	Feed line length and width
$L_g, W_g$	-	Ground plane length and width
$t$	-	Copper patch thickness
$Dh$	-	Distance between the edge of the patch and the ground plane
$\tan\delta$	-	Tangent dielectric loss angle
$S_{cpw}$	-	Gap between CPW-fed wire and the ground plane
$f_{notch}, f_n$	-	Notched frequency
$L_{slot}$	-	Slot's length
$\rho_e$	-	Envelope correlation coefficient
$\pi$	-	Constant, the ratio of a circle's circumference to diameter
$R, L, C$	-	Resistor, inductor, and capacitor
$Z_0$	-	377 $\Omega$ free space wave impedance
$A_1$ and $A_2$	-	Areas of the ground plane and the radiation patch
$Z_a$	-	Antenna impedance
$L_s$	-	Horizontal length of meander-line strip arms
$L_z$	-	Vertical length of meander-line strip arms
$th_s$	-	Width of meander-line strip arms
$L_{strip}$	-	Total length of meander-line strip arms
$T_{p1}, T_{p2}, W_{p1}$	-	T-strip lengths and width
$g_{sp}$	-	Gap between the T-strip and the radiator patch
$c$	-	Speed of light
$s$	-	Spacing between the metal of FSS unit cells
$T_{fsb}$	-	Substrate thickness of FSS unit cell
$D_x, D_y$	-	Physical dimensions width and length of the unit cell
$g, L_{fs}$	-	Square ring width, Square ring length
$W_{fc}, L_{fc}$	-	Cross-dipole width, Cross-dipole length
$n$	-	Constant
$\emptyset$	-	Phase

$\beta$	-	Propagation constant of free space
$\theta$	-	Angle of incidence wave on the FSS unit cell
$An_{eff}$	-	Effective angle of incidence wave on the FSS unit cell
$\Delta x, \Delta y$	-	Step shift of xy scanning plane



**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Fabrication Process	184
B	Parametric study of the hexagonal radiation patch	185
C	Parametric study of notching interfered bands	188
D	Parametric study of frequency selective surface (FSS)	192
E	Vector Fitting and SPICE algorithms for equivalent circuit	198



PTTA UTHM  
PERPUSTAKAAN TUNKU TUN AMINAH

## **CHAPTER 1**

### **INTRODUCTION**

This chapter presents the research motivation, a short background, the problem statement, the objectives, and the scope of this work. Section 1.1 describes the events and the existing technologies that offer significant motivations to carry out this study. The UWB standard and followed by a short background about implementing UWB systems for microwave imaging (MWI) applications are discussed in Section 1.2 and 1.3, respectively. Describing the general problem, several existing issues, and the research direction to fill a gap are elaborated in Section 1.4. The objectives, aim, scope, and the contributions of this study are described in Sections 1.5, 1.6, and 1.7, respectively. Lastly, Section 1.8 briefly reposts the thesis organisation. The details are depicted in the following sections.

#### **1.1 Motivation**

Some horrendous events of attacks, such as the September 11 2001 New York City twin towers attack, 2004 Madrid train attack, and 2007 London car bombings, have generated new security adoption processes across the globe. Hence, as a safety measure, the Schiphol airport has begun scanning passengers' body since 2007 [1]. Safeguarding humans from potential attackers have become a top priority. With various cutting-edge approaches devised by attackers to circumvent security inspection, a strong need is present to perform quality security screening in airports and public transportations [2]. While thousands of strangers arrive and depart every single day through airplanes, international airports are the most critical public

transportation constrictions. Thus, both international and local airports have been supported by state-of-the-art security systems and devices [2].

Typically, the conventional scanners in airports are X-ray machines. Passengers are required to take-off all their belongings at the security terminal of both local and international airports. The checklist includes wallets, handbags, hats, keys, and phones, to name a few. Next, the belongings are arranged in a plastic box and scanned using the X-ray system machine. Laptops, cans, and containers exceeding 100 ml must be removed from the handbags, and arranged in a box to be scanned by X-ray scanner. This process lengthens the time of loading the luggage bags into the airplane and takes up passengers' time, especially those with short transit trips. Nevertheless, this process is essential because security rules are significant to prevent weapons, such as bombs and handguns, from being carried onto the airplane [3].

Despite the low-resolution display of two-dimensional (2D) images, X-ray poses health risks due to its high ionising radiation towards human tissues [1]. Meanwhile, terahertz radar offers high-resolution images, but its high cost and short distance limit its application at the airports [2].

Airway companies have taken measures by increasing scanner accuracy and time efficiency through enforcement of baggage-screening procedure, but often at the cost of increased waiting time and ticket price [4]. The highlighted concerns had motivated the researcher to develop a modern radar system in the attempt of overcoming these issues that have always remained top security priority. The key solution is by using MWI based UWB system for indoor security purposes [2], which refers to one of the most sought topics in the radar-imaging field. The details of standardisation and regulations of the UWB technology are presented in the next sections.

## **1.2 UWB standard and regulation**

UWB communication uses very narrow RF pulses between the receiver and the transmitter for communication purposes. Short-duration pulses generate extensive bandwidth and have many other advantages, thus are the building blocks for wireless communication. There are many types of waveband signals in a UWB, such as



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